IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

# Methods for verification of groundwater flow simulators (case study: Jakarta groundwater basin in the urban villages of Jatiluhur and Jatirangga, Bekasi City)

To cite this article: T Rahmawati *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **633** 012014

# Methods for verification of groundwater flow simulators (case study: Jakarta groundwater basin in the urban villages of Jatiluhur and Jatirangga, Bekasi City)

**T Rahmawati[1], G L Putri[2], D R Marthanty[1], F Zulkarnain[3], C R Priadi[1,2 *]**

1 Civil and Environmental Engineering Department Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia
2 Center for Sustainable Infrastructure Development, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia
3 Geography Department, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok, 16424, Indonesia
E-mail: crpriadi@ui.ac.id

**Abstract.** Limited access to clean water leads to residents extracting groundwater through dug wells or boreholes, which in turn results in groundwater becoming contaminated. Groundwater flow simulation of the Jakarta basin, which has been previously modeled with the *Groundwater Modeling System 10.3,* can be used as a basis for simulating groundwater flow pollution. Before simulating the groundwater flow pollution, the groundwater flow simulator needs to be verified to examine whether simulators and conditions in the field correspond to the water table level. This study demonstrated the methodology used for verification of the simulator in research. Verification was done using the Chi-square method. The results revealed that calculated Chi-square values were larger than Chi-square table values for the two urban villages of Jatiluhur and Jatirangga. The value of calculated Chi-square value for Jatiluhur was 17.3, whereas it was 7.81 in the Chi-square table. In Jatirangga, the calculated Chi-square value was 37.23, whereas it was 14.1 in the Chi-square. Results indicated that the simulation was not in accordance with the actual water table level. This discordance can occur since it necessary to update the data on groundwater flow simulation results with bore log data or to verify the hydrodynamic conditions of the study area.

## 1. Introduction

Utilization of groundwater for daily needs is a factor affecting groundwater balance. Changes in groundwater level due to uncontrolled groundwater extraction can result to a reduction in the age of deep groundwater (in confined areas), leading to surface water entering deep groundwater and contaminating deep groundwater [1]. In addition, residents can also face difficulties in accessing clean water from groundwater because the groundwater level of the well decreases significantly, whereas the supply of clean piped water in the area might still be limited.

In groundwater basins, fundamental components include recharge and discharge areas. To study the behavior of real systems in the field, it is necessary to simulate the process of implementing the model into a computer program and execute it in a manner that resembles the system in the field [2]. Previously, a groundwater management simulation was conducted in the Jakarta groundwater basin [1]. The aim was to simulate the groundwater hydrodynamic condition of the Jakarta groundwater basin in order to conduct various policy simulations related to groundwater contour. The simulator refers to the Jakarta groundwater basin, which includes Bekasi City in the urban villages of Jatiluhur and Jatirangga. The simulator was made using the Groundwater Modeling System (GMS) software 10.3. Modules used included 2D Grid, 3D Grid, and Borehole, whereas the model used was MODFLOW. The input parameters of the simulator manufacture consisted of horizontal and vertical boundary conditions, soil contour and ground water level, initial conditions, general head values, specific head values, aquifer hydraulic parameters, river boundaries, lakes, recharge wells, and groundwater extraction. The data for these parameters were obtained from secondary data, which was then used to simulate the hydrodynamic process that occurs in the Jakarta groundwater basin.

Jatiluhur and Jatirangga, two urban villages in Bekasi City, are included in the Jakarta groundwater basin. The Jakarta groundwater basin is a basin that is bounded by a free groundwater level at the top and a tertiary-aged rock (impermeable) at the bottom [3]. The northern part of the Jakarta groundwater basin is bounded by the Java Sea with a constant head boundary value of 0; in the western part, there is the Cisadane River, which is included in the no flow boundary; furthermore, the eastern part is bounded by the Cikeas River and the Bekasi River, and the southern part is bounded by rocks that arise in the Bulak Kulon area encompassing Depok City and which is considered as the groundwater flow limit because groundwater flow originating from the south of Depok is relatively small at 1 $m^3$ per year [1].

Model verification and simulation are required to assess modeling accuracy and uncertainty [4] and to measure the suitability of the simulation results in terms of whether they approach field conditions or not. The more the simulation results correspond with field conditions, the better the simulator is in describing field conditions. Generally, modeling verification is done using statistical comparison methods. One method includes the Chi-square method. A simulator, such as the one utilized by Apriatresnayanto in 2018 [1] is necessary to see the actual conditions on the ground. The purpose for the verification of this groundwater flow simulator is to analyze the results of the simulator and calibrate the model with newer data, including more pumping test data to obtain better aquifer parameter results. The purpose of this study is to describe the method used to verify simulation results and field conditions using the Chi-square test.

## 2. Materials and methods

### *2.1. Groundwater level measurement*

Groundwater has certain characteristics in terms of its movement patterns, seepage, and other features. Groundwater flows with a certain movement pattern and velocity, and differences in soil properties between permeable media and other permeable media [5]. Groundwater level refers to the surface of a groundwater body that is pressurized by atmospheric air [6]. Based on SNI 7749: 2012 procedures for determining groundwater levels in boreholes or monitoring wells, there are three measurement methods: a ballast gauge, a sound measuring instrument, and an electric flame meter. However, measuring instruments with sound marks can only be utilized in boreholes or wells that have shallow ground water levels. Groundwater level gauges have both advantages and disadvantages. Measurement with weights produces the highest accuracy; however, the measuring tape used must clearly reflect the difference between wet and dry tape.

### *2.2. Research sites*

The study sites included the Jakarta groundwater basin, specifically the Jatiluhur and Jatirangga urban villages in Bekasi City, West Java (hereinafter referred to as Jatiluhur and Jatirangga). The selection of research sites was based on several considerations and conditions, including the level of poverty seen at the sub-district level and at the urban village level, population density at the sub-district level, hydrogeological conditions, such as the surface conditions below which are still included in the Jakarta groundwater basin, aquifer productivity, and distance of pollutant sources to groundwater sources. Four points in the Jatiluhur area and eight points in the Jatirangga area were included. Figure 1 shown the points on Bekasi City. The orange area is Jatiluhur, and purple area is Jatirangga.

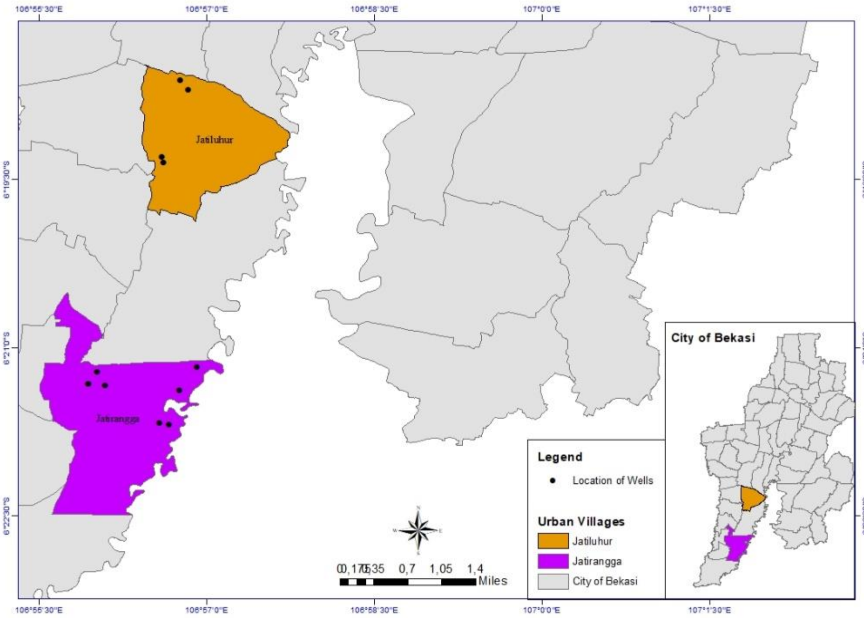


**Figure 1.** Research Location

*2.3. Regional condition of research area*

The bottom of the aquifer system of the Jakarta groundwater basin is formed by opaque Miocene sediments, which are also outcrops in the southern boundary of this basin. The Jakarta groundwater basin consists of sea Pliocene and Quaternary sand and delta sediments up to 300 m. Quaternary sediments are divided into three aquifer systems based on hydraulic characteristics and depth, namely, phreatic aquifer systems (0 to -40 m), upper confined aquifer systems (-40 m to -140 m), and bottom depressed aquifer systems. The average horizontal hydraulic conductivity value is approximately $1 \times 10^{-3}$ cm.s$^{-1}$, and the hydraulic conductivity value is roughly $1 \times 10^{-5}$ cm.s$^{-1}$ [5]. In Figure 2, the yellow area represents the Jakarta groundwater basin.

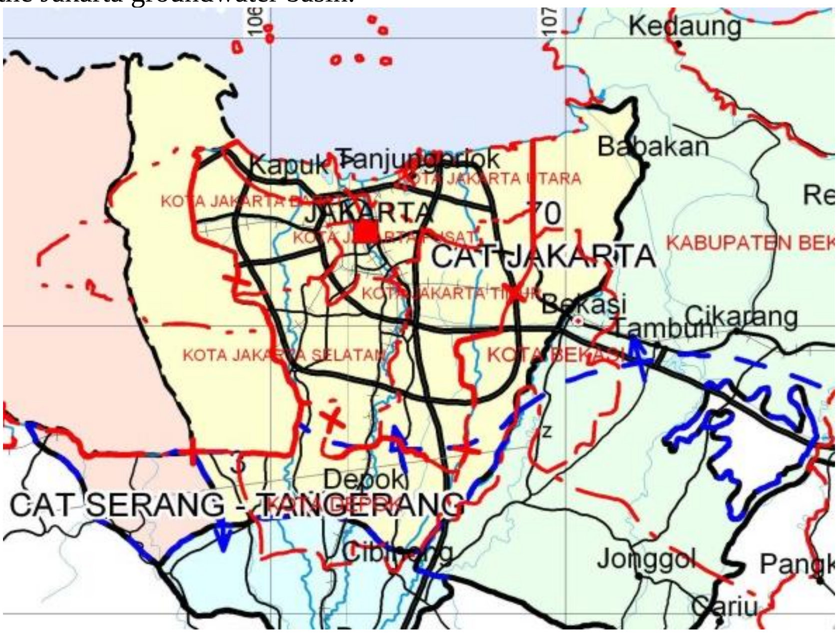


**Figure 2.** Map of the Jakarta groundwater basin.

IOP Conf. Series: Earth and Environmental Science **633** (2021) 012014 doi:10.1088/1755-1315/633/1/012014

### *2.4. Chi-square test*

Verification is a necessary step for model acceptance [6]. One verification method includes the Chi-square test. The Chi-square test is a non-parametric statistical test. Hypothesis testing for differences in more than two proportions of a population cannot use T or F distribution; however, it can use the Chi-square distribution. The Chi-square test belongs to the class of statistical hypothesis-testing mechanisms and is commonly used to determine whether the assumed mean and covariance matrices match the actual settings or not [7].

### *2.5. Data*

At the research locations in Jatiluhur and Jatirangga, Bekasi City, it was found that there were 12 dug wells that could be measured in depth using fiberglass measuring tapes, and their coordinates were recorded. Of the 12 dug wells, four of them were located in Jatiluhur, and eight of them were located in Jatirangga. The depth of the wells in the field varied from 9 to 29 m. Based on the depth of the well, this value was compiled with GPS-recorded data relating to altitude in the field. The results of measurements in the field are shown in Table 1. The HH ID column shows the measurement point name for the depth of the dug wells at the study site. The depth of the groundwater level was obtained from the altitude (Z) value minus the measurement results of the well depth.

**Table 1.** Coordinates and depth of groundwater level

| Urban Villages | Sample Code | Latitude (East, X) | Longitude (North, Y) | Altitude in Field (Z) | Depth of Well (meter) | Water Table Level (meter) |
|---|---|---|---|---|---|---|
| Jatiluhur | JL1 | 715414 | 9301945 | 79.7 | 9 | 70.7 |
| | JL2 | 715282 | 9302101 | 57.5 | 10 | 47.5 |
| | JL3 | 715011 | 9300747 | 78.5 | 14 | 64.5 |
| | JL4 | 714980 | 9300835 | 85.0 | 12 | 73.0 |
| Jatirangga | JR1 | 713749 | 9297110 | 88.3 | 12 | 76.3 |
| | JR2 | 713759 | 9297104 | 60.7 | 18 | 42.7 |
| | JR3 | 714028 | 9297075 | 70.3 | 7.5 | 62.9 |
| | JR4 | 713896 | 9297305 | 72.5 | 12.3 | 60.5 |
| | JR5 | 715080 | 9296424 | 72.2 | 17 | 55.2 |
| | JR6 | 714921 | 9296452 | 84.6 | 29 | 55.6 |
| | JR7 | 715251 | 9296994 | 82.0 | 12 | 70.0 |
| | JR8 | 715548 | 9297369 | 80.2 | 11.2 | 69.0 |
| Mean | | | Jatiluhur | 75.2 | 11.3 | 63.9 |
| | | | Jatirangga | 76.4 | 14.8 | 61.5 |
| Standard Deviation | | | Jatiluhur | 12.1 | 2.2 | 11.5 |
| | | | Jatirangga | 9.0 | 6.6 | 10.5 |

The next dataset used included head values from the results of Jakarta groundwater basin flow simulator that were collected previously by Apriatresnayanto in 2018 with *Groundwater Modelling System 10.3* [1]. The results of the simulators used are from simulations with groundwater extraction scenarios using residents' dug wells or borehole. Groundwater retrieval by residents mostly occurs in buffer areas, such as the cities of Depok, Bekasi, and Tangerang, which can cause the pattern of groundwater contour to change when compared to systems without groundwater uptake. Intake of groundwater from the wells of these inhabitants affects basins in several places. The simulation results are depicted in Figure 3. The simulation of groundwater basin flow can be a basis for building the simulation for contaminant flow in

IOP Conf. Series: Earth and Environmental Science **633** (2021) 012014 doi:10.1088/1755-1315/633/1/012014

groundwater. Tracer for contaminant flow in the simulation refers to the concentration of total dissolved solids (TDS) in residential areas, which describe pollutants generated from population sanitation facilities, such as septic tanks and ponds connected to toilets for fecal containment.

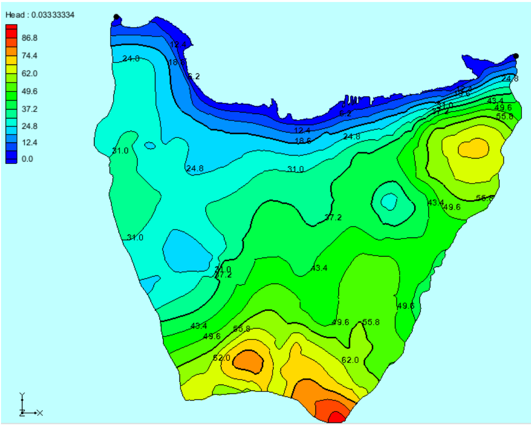

**Figure 3.** Simulation results of groundwater flow using groundwater near a community well (shallow well) [1].

## 3. Results

The verification test can be conducted by comparing the results head of the groundwater flow simulator of the Jakarta groundwater basin and the results of the water table level measurements at the several points included in the groundwater basin. Head is the water table level of the groundwater flow simulation. Twelve dug wells were measured at groundwater level. For the locations of the 12 dug wells, the head values were determined from the results of the simulation of ground flow, which had been previously simulated with the help of GMS 10.3 (MODFLOW) software [1]. Based on the results of water table level in field measurements, significant differences compared to the results of the simulator were observed. Head of simulation values tended to be stable at values ranging from 45.0 to 49.6 m, whereas the depth of the groundwater level ranged from 42.7 to 76.3 m. The differences between head of simulation and depth of the groundwater level values are depicted in Table 2.

**Table 2.** *Head* from simulation and groundwater level depth

| Urban Villages | Sample Code | Water Table Level (meter) | *Head of Simulation* |
|---|---|---|---|
| Jatiluhur | JL1 | 70.7 | 49.6 |
| | JL2 | 47.5 | 49.6 |
| | JL3 | 64.5 | 49.6 |
| | JL4 | 73.0 | 49.6 |
| Jatirangga | JR1 | 76.3 | 45.0 |
| | JR2 | 42.7 | 45.0 |
| | JR3 | 62.9 | 47.0 |
| | JR4 | 60.5 | 45.0 |
| | JR5 | 55.2 | 45.0 |
| | JR6 | 55.6 | 45.0 |
| | JR7 | 70.0 | 49.6 |
| | JR8 | 69.0 | 48.0 |
| Mean | Jatiluhur | 63.9 | 49.6 |

| | | | |
|---|---|---|---|
| | Jatirangga | 61.5 | 46.2 |
| Standard Deviation | Jatiluhur | 11.5 | 0.0 |
| | Jatirangga | 10.5 | 1.8 |

The altitude of the field, the groundwater level, and the simulated groundwater level demonstrated trends that were mutually sustainable with each other. Figures 4 and Figure 5 shown the comparison of these parameters in Jatiluhur and Jatirangga.

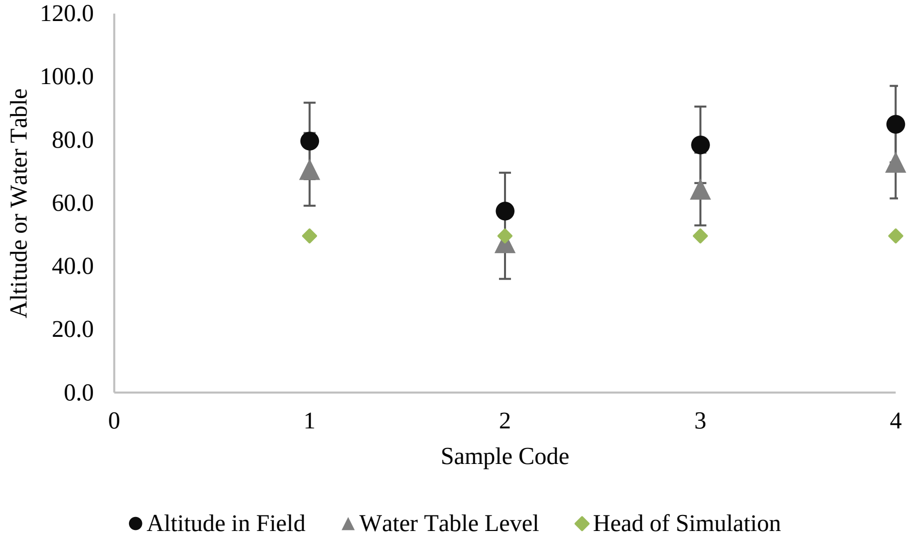


**Figure 4.** Comparison of Altitude in Field, Water Table Level, and Head of Simulation in Jatiluhur Urban-Village

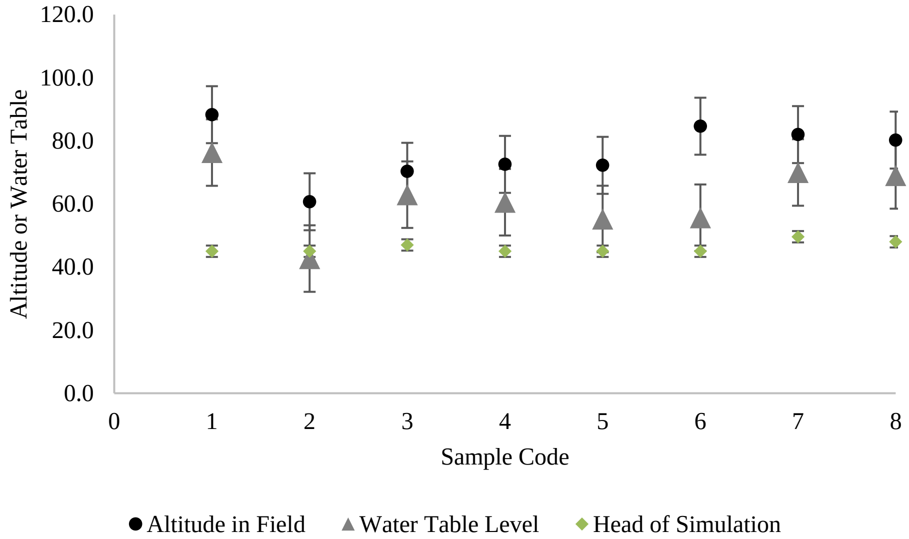


**Figure 5.** Comparison of Altitude in Field, Water Table Level, and Head of Simulation in Jatirangga Urban-Village

The difference in the head of the simulation results compared with the depth of the groundwater level in the field was then subjected to a verification test using the Chi-square method. Before doing the calculations, it was first necessary to make a hypothesis. The hypothesis consists of $H_0$ and $H_1$. $H_0$ states that the simulation results data are in accordance with the conditions in the field, whereas $H_1$ states that the simulation results is not in accordance with the conditions on the ground. There are two rules used in this method. The first rule states that if the Chi-square count results are smaller than those of the Chi-square table, $H_0$ is accepted, and $H_1$ rejected. The second rule states that if the Chi-square count is greater than the Chi-square table, then $H_0$ is rejected, and $H_1$ is accepted.

These hypothesis was used as a basis for decision making of verification result. The depth of the groundwater level was compared with the head value resulting from groundwater flow simulation. After that, a verification test was conducted using the Chi-square method and compared with the Chi-square values contained in the table. Chi-square calculation was done according to Equation 1:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

Where the $O_i$ is an observation data value (simulation data - i), and $E_i$ is an expected data value (theoretical data or the $i$-th real system).

After obtaining the Chi-square values from the calculation, it was then compared with the Chi-square values from the table according to the degree of freedom and significance level. The degree of freedom was obtained from the number of samples minus 1 ($n$-1). In this study, verification tests were conducted on 12 dug wells. The degree of freedom was 11. The level of significance, also known as α, is a measure of how much confidence will be taken. The value of α used was 0.05, and the confidence level of the decision taken was 95%.

The calculated Chi-square values and Chi-square table values are depicted in Table 3. Results revealed that calculated Chi-square values were larger than Chi-square table values for both Jatiluhur and Jatirangga. The calculated Chi-square value for Jatiluhur was 17.3, whereas it was 7.81 for the Chi-square table. In Jatirangga, the calculated Chi-square value was 37.23, whereas for the Chi-square table, it was 14.1. Such results mean that $H_0$ is rejected, and $H_1$ is accepted; in short, the simulation was not in accordance with the water table level. This can occur because it is necessary to update the data on groundwater flow simulation results with bore log data or to verify the hydrodynamic conditions of the study area.

**Table 3.** Value of Chi-square Calculated and Chi-square Table

| Sample Code | Chi-square Calculated | | Chi-square Table |
|---|---|---|---|
| JL1 | 6,29 | 17,30 | 7,81 |
| JL2 | 0,09 | | |
| JL3 | 3,42 | | |
| JL4 | 7,50 | | |
| JR1 | 12,83 | 37,23 | 14,1 |
| JR2 | 0,13 | | |
| JR3 | 4,04 | | |
| JR4 | 3,99 | | |
| JR5 | 1,89 | | |
| JR6 | 2,03 | | |
| JR7 | 5,93 | | |
| JR8 | 6,40 | | |

## 4. Conclusion

Verification test results of the simulation and field conditions can be conducted using the Chi-square method through manual calculation. Before calculating the value of Chi-square, it is necessary to formulate a hypothesis in advance regarding the relationship between the calculated Chi-square values and Chi-square table values. The results of the current study indicate that calculated Chi-square values were larger than Chi-square table values for both Jatiluhur and Jatirangga. This means that $H_0$ is rejected and that $H_1$ is accepted, such that the simulation is not accordance with the water table level. To ensure that simulation results are in accordance with field conditions, the calculated Chi-square value must be smaller than the Chi-square table value. There are a few reasons why the simulation may be discordant with the actual water table level. This can occur when data on groundwater flow simulation results is not updated with bore log data or when the verification of hydrodynamic conditions of the study area and simulators has not been conducted.

## 5. References

[1] Apriatresnayanto R 2019 Jakarta Groundwater Basin Recharge - Discharge Boundary Area Map: A Preliminary Study. *IOP Conf. Series: Materials Science and Engineering* 690

[2] Sridadi B 2009 *Modelling and Simulation System*, (Jakarta: Informatika).

[3] Mukhtar O, Pranantya P A and Hadian S D 2019 Groundwater Management in DKI Jakarta Groundwater Basin. *3rd National Seminar of Geological Engineering Universitas Padjadjaran*

[4] McFarland J and Mahadevan 2008 S Multivariate significance testing and model calibration under uncertainty *Computer Methods in Applied Mechanics and Engineering* 197 p 2467-2479.

[5] Simaremare S 2015 One-Dimensional Groundwater Flow Analysis *Electronic Journal of Civil and Environmental Engineering, Unsri* 783-794.

[6] National Standardization Agency of Indonesia. 2012 Indonesian National Standard Number 7749 - Procedure for Determination of Groundwater Surface at the Borehole or Monitor Well (Jakarta: BSN Indonesia)

[7] Mayer D and Butler D 1993 Statistical Validation *Ecological Modelling* 21.

**Acknowledgements**

This research was funded by the Water for Women Fund from the Australian Government Department of Foreign Affairs and Trade (number WRA1:1004) and also by PTUPT from the Ministry of Research, Technology and Higher Education of Indonesia (number: ADD-NKB-2943/UN2.RST/ HKP.05.00/2020). We thank Juliet Willetts, Tim Foster, and Fransziska Genter from University of Technology Sydney and Angela Harris from North Carolina State University for their extraordinary discussion, knowledge sharing, and collaboration in this research.